On the Possibility that MgII Absorbers Can Track the Merger Evolution of Galaxy Groups from High Redshift

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Abstract. The properties of MgII absorption–selected systems show a large variety of kinematics and higher ionization conditions. A multivariate taxonomic study of MgII absorbers has yielded an "extreme" class of "Double" systems. These Double systems are characterized by kinematic velocity spreads up to 400 km s^{-1}, and by twice the Lyα, MgII, and CIV absorption strengths of the more typical, "Classic", MgII system. Evolution in the number per unit redshift of these systems is compared to the redshift evolution in the number of close pairs of galaxies. It is found to be a plausible scenario that Double systems arise in small groups of galaxies, implying that they might trace close pair evolution to high redshifts.

1. Motivations: Why Study MgII Systems?

One of the central motivations for studying intervening quasar absorption lines, is that they provide insights into galactic evolution from the perspective of the chemical, ionization, and kinematic conditions of interstellar, halo, and intra-group gas. In this contribution, a "new" taxonomy of absorption line systems is presented, one in which equal, simultaneous consideration is given to the HI, MgII, FeII, and CIV absorption strengths and to the gas kinematics. Details of the work presented here can be found elsewhere (Churchill 1997; Churchill et al. 1999a,b,c). Here, we investigate an extreme, rapidly evolving, class of MgII system and discuss the possibility that its further study may provide insights into the evolution of clustering on the scale of galaxy groups.

Arguably, the MgII–selected systems at $z \leq 1$ are best suited for a taxonomic study of absorption systems because: (1) their statistical (Lanzetta, Turnshek, & Wolfe 1987; Steidel & Sargent 1992) and kinematic (Petitjean & Bergeron 1990; Churchill 1997; Charlton & Churchill 1998) properties are thoroughly documented, (2) they arise in structures possessing a wide range of HI column densities, including sub–Lyman limit (Churchill et al. 1999, 1999a), Lyman limit (e.g. Steidel & Sargent 1992), and damped Lyα (e.g. Rao & Turnshek 1998; Boissè et al. 1998) systems, (3) they give rise to a range of CIV absorption strengths (Bergeron et al. 1994; Churchill et al. 1999b,c), and (4) those with rest–frame equivalent widths, $W_r(\text{MgII})$, greater than 0.3 Å are associated with normal, bright galaxies (Bergeron & Boissé 1991; Steidel, Dickinson, & Persson 1994; Churchill, Steidel, & Vogt 1996; Steidel 1998).

2. Ionization, Kinematics, and Absorber Taxonomy

The Mg II kinematics, and the Mg II, Fe II, C IV, and Lyα absorption strengths, were studied for 45 Mg II absorption–selected systems with redshifts 0.4 to 1.4. The kinematics of the Mg II and Fe II absorption was resolved at $\simeq 6$ km s^{-1} resolution with the HIRES instrument (Vogt et al. 1994) on Keck I. The Lyα and C IV absorption was obtained from the *HST* archive of FOS spectra. These UV spectra have resolution $\simeq 230$ km s^{-1}, so that the detailed kinematics of the neutral and high ionization gas are not available for study. See Figure 1 for an example of the data.

For any given W_r(Mg II), there is a large, ~ 1 dex, variation in the ratio W_r(C IV)/W_r(Mg II) (Churchill et al. 1999b,c). This indicates a large spread in the global ionization conditions in Mg II absorbers, and by implication, the ISM, and halos of the host galaxies, and possibly the intragroup media when small groups are intercepted by the line of sight. It was also found that W_r(C IV) is strongly correlated to the Mg II kinematics (Churchill et al. 1999a,c), where the kinematics is quantified using the second velocity moment of the Mg II $\lambda 2796$ optical depth. As such, there is a strong connection between the kinematic distribution of the low ionization gas and the presence of a strong, high ionization phase. For the majority of the systems, the gas must be multiphase in that a substantial fraction of the high ionization gas arises in a physically distinct phase from the lower ionization gas (Churchill et al. 1999c; also see Churchill & Charlton 1999).

A clustering analysis (tree and K–means) was used to examine multivariate trends between the Mg II kinematics, and Mg II, Fe II, Lyα, and C IV absorption strengths. To a high level of significance (greater than 99.99% confidence), it was found that the properties of Mg II systems can be organized into five classes, which we have called "DLA/H I–Rich", "Double", "Classic", "C IV–deficient", and "Single/Weak". An example system for each of the five classes is shown in Figure 1. Ticks above the Mg II and Fe II profiles (HIRES/Keck) give the velocities of the multiple Voigt profile components (Churchill 1997) for the singly ionized gas and ticks above the Lyα profile and both members of the C IV doublet (FOS/*HST*) show the expected location of these components for the neutral and higher ionization gas.

3. The Double Systems

In view of the topic of the meeting, we focus here on the Double systems, since they may provide clues to the clustering of material at higher redshifts. We present the HIRES/Keck Mg II $\lambda 2796$ profiles of Double systems, including a few at $z > 1.4$, in Figure 2. Though Churchill et al. (1999) suggested that Double systems may be associated with later–type galaxies undergoing concurrent star formation (i.e. the multiphase gas arises in superbubbles and from outflows, or chimneys, similar to the gaseous components of the Galaxy), there are at least two other obvious explanations for Double systems.

The first scenario is that they might be two Classic systems nearly aligned on the sky and clustered within a ~ 500 km s^{-1} velocity separation (i.e. galaxy pairs). An example of this scenario, at $z \simeq 0$, is observed in the spectrum of
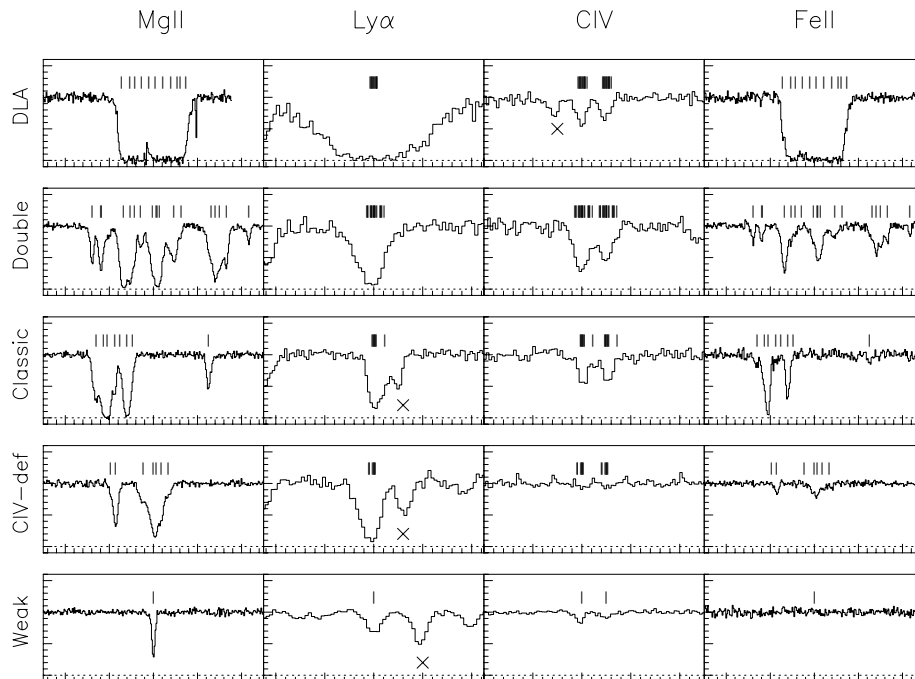
Figure 1.   Examples of the five taxonomic classes of $z \sim 1$ Mg II absorbers based upon Mg II, Lyα, C IV, and Fe II absorption (left to right).   The Mg II and Fe II profiles, shown over a velocity window of 460 km s^{-1}, are measured at $\simeq$ 6 km s^{-1} resolution (HIRES/Keck). The Lyα and C IV profiles, shown over a velocity window of 1300 km s^{-1}, are observed in the UV (FOS/*HST*) with resolution $\simeq$ 230 km s^{-1}. The five classes (top to bottom) are DLA, Double, Classic, C IV–deficient, and Weak. See text for further details.

SN 1993J (Bowen, Blades, & Pettini 1995). The SN 1993J line of sight probes half the disk and halo of M81, half the disk and halo of the Galaxy, and the "intergalactic" material apparently from the strong dwarf–galaxy interactions taking place with both galaxies. The M81/Galaxy Mg II $\lambda 2796$ absorption profile has a virtually identical kinematic spread, saturation, and complexity as that of the $z = 1.79$ absorber toward Q 1225 + 317 (Figure 2). Double systems constitute $\simeq$ 7% of our sample. Interestingly, at $z \sim 0.3$, roughly 7% of all galaxies are observed to be in "close physical pairs" (Patton et al. 1997), where a pair has a projected separation less than 20 h^{-1} kpc. Even accounting for the evidence that this fraction increases with redshift (e.g. Neuschaefer et al. 1997), the fraction of Double systems in our sample is consistent with that of galaxy pairs at intermediate redshifts.

The second scenario is that Double systems may consist of a primary and a satellite galaxy (e.g. York et al. 1986), possibly in a group environment. Using the Local Group as a model and applying the simple cross–sectional dependence for W_r(Mg II) with galaxy luminosity (Steidel 1995), the probability of intercepting a "double" absorber for a random line of sight passing through a "Milky Way" galaxy in a "Local Group" was estimated (see Charlton & Churchill 1996).
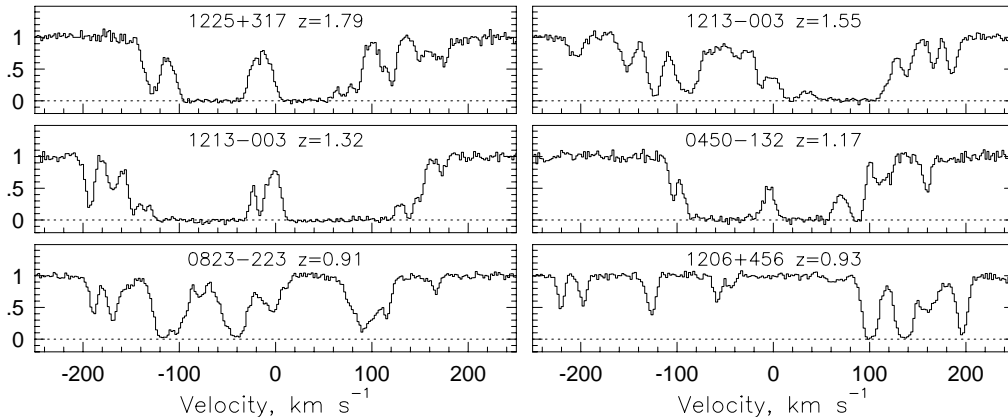
Figure 2. The $\lambda 2796$ transitions (HIRES/Keck) of several higher redshift systems with $W_r(\mathrm{Mg\,II}) \geq 1.0$ Å. These systems exhibit the characteristics expected from close pairs of galaxies (see Bowen et al. 1995).

Though the results are fairly sensitive to the assumed gas cross sections of small mass galaxies, we find a $\sim 25\%$ chance of intercepting both the LMC and the Milky Way, and a $\sim 5\%$ chance of intercepting both the SMC and the Milky Way. All other galaxies in the Local Group have negligible probabilities of being intercepted for a line of sight passing with 50 kpc of the Milky Way. If, at $z \sim 1$, roughly 30% of all galaxies typically have one LMC–like satellite galaxy within 50 kpc (see Zaritsky et al. 1997), it could explain the observed fraction of "Double" systems found in our sample.

4. Galaxy Group Evolution

If most Double systems arise in the environments associated with galaxy pairs, then the redshift evolution observed in the number of galaxy pairs would necessarily need to be in step with the evolution in the class of "Double" Mg II absorbers themselves. Over the redshift interval $1 \leq z \leq 2$, it is seen that the galaxy pair fraction, evolves proportional to $(1+z)^p$, with $2 \leq p \leq 4$ (Neuschaefer et al. 1997). This compares well with $p = 2.2 \pm 0.7$ for very strong Mg II absorbers with $W_r > 1.0$ Å (Steidel & Sargent 1992). As such, galaxy pair evolution remains a plausible scenario for explaining the observed evolution in the class of the largest equivalent width Mg II absorbers (illustrated in Figure 2).

None of these arguments are conclusive, nor absolutely compelling in the face of several attractive scenarios (i.e. intergalactic infall, star forming events, etc.) that are equally consistent with the available data. Even so, the hypothesis that the strongest, most kinematically complex Mg II absorbers arise in galaxy groups or pairs is directly testable, and is thus useful for future investigations that probe galactic evolution from the point of view of absorption line systems. Deep imaging and redshift confirmation of the galaxies associated with Double systems and searches for high ionization intragroup gas, such as N V and O VI (Mulchaey et al. 1996), may confirm this hypothesis.

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